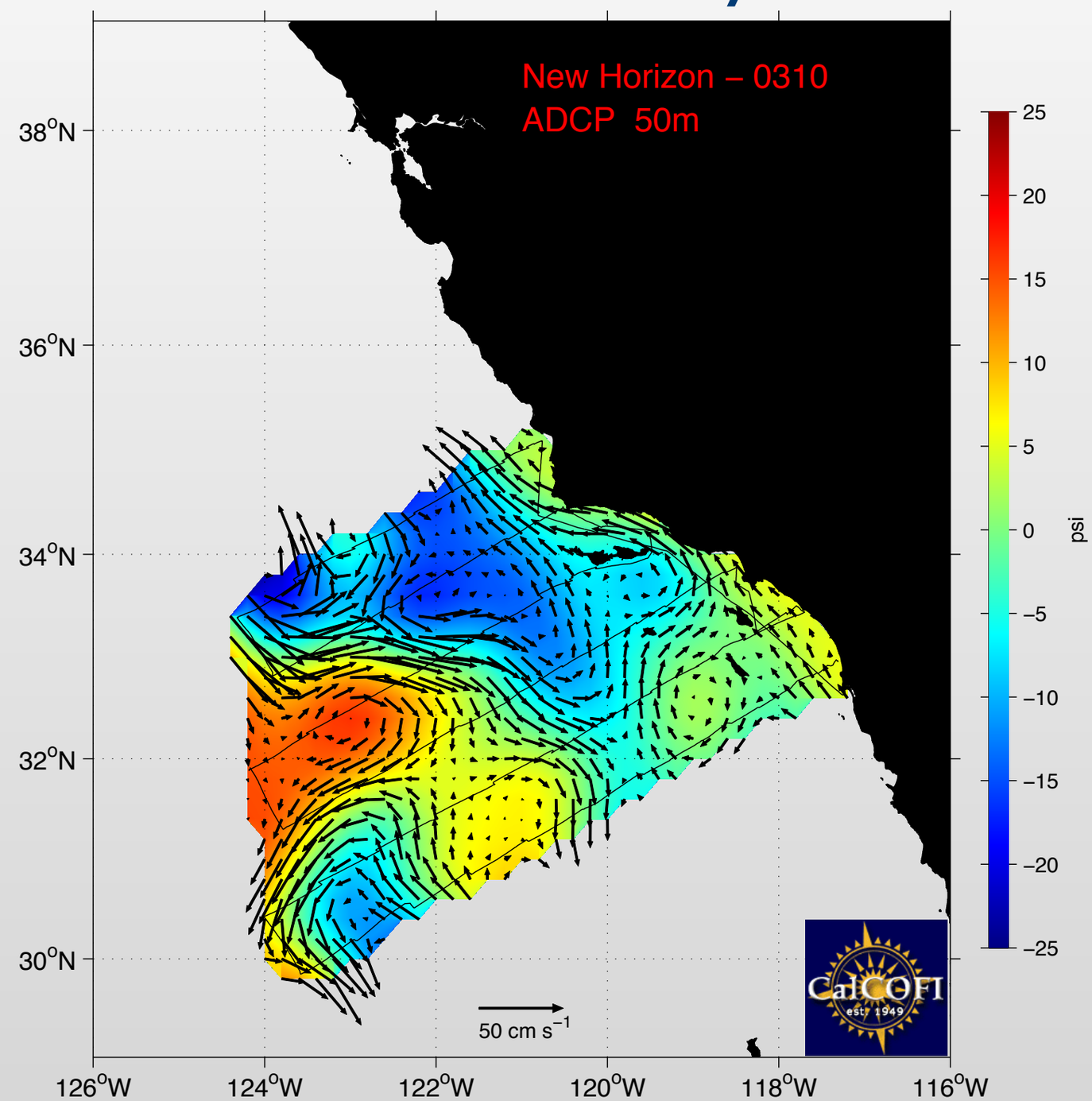
Characterizing the Transition from Balanced to Unbalanced Motions in the Southern California Current System

Teresa Chereskin
Cesar Rocha
Sarah Gille
Scripps Institution of Oceanography

Dimitris Menemenlis
Jet Propulsion Laboratory

Marcello Passaro
Deutches Geodätisches Forschungsinstitut der Technischen Universität München

Funding: NASA Ocean Surface Topography Team, SWOT SDT

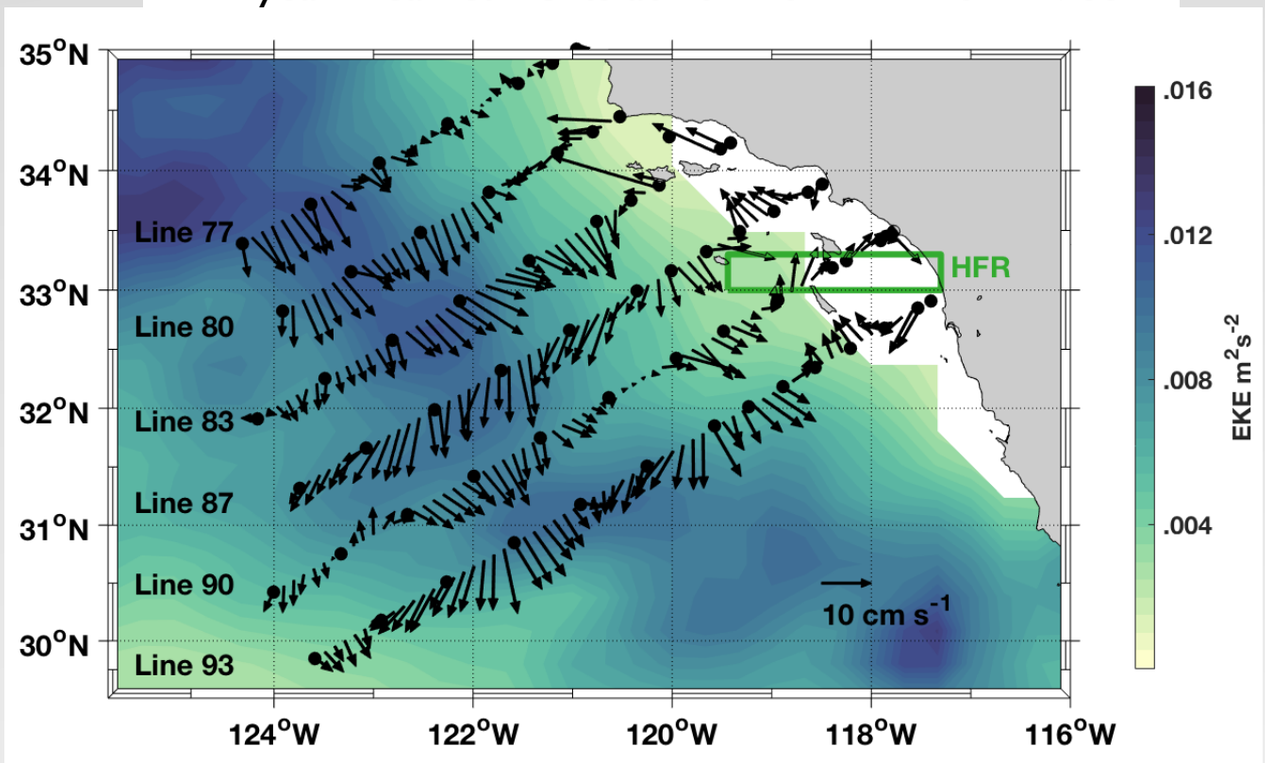


Observations

Currents from CalCOFI ADCP:

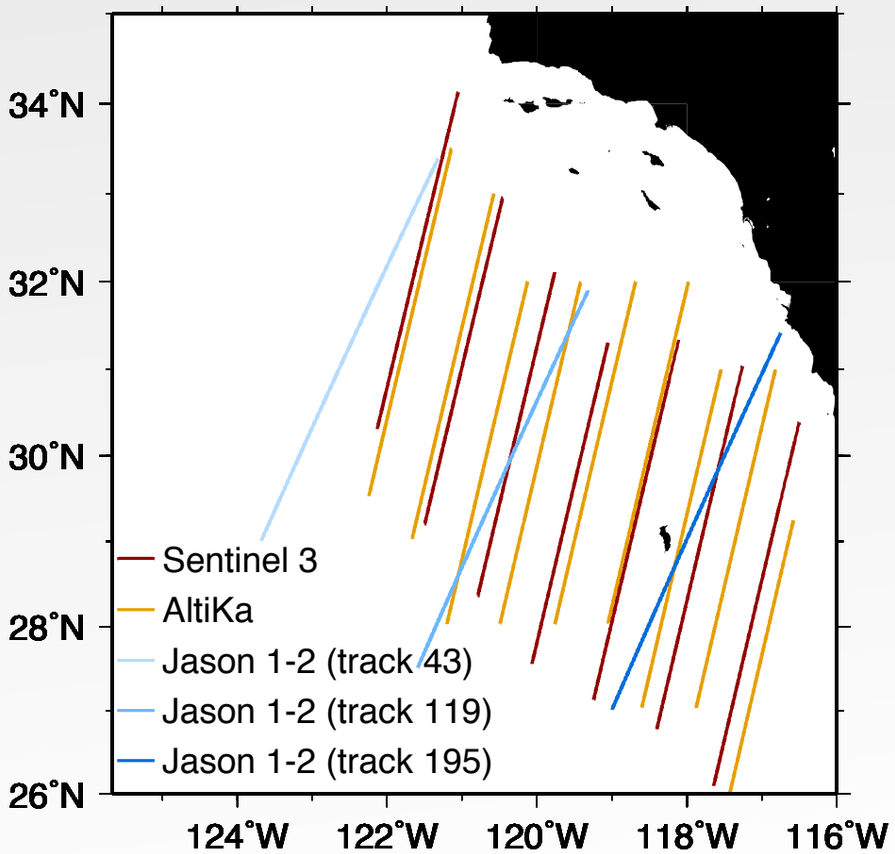
- sampled 4x/year along 6 lines
- horizontal resolution: 5 km
- depth range: 20 m to 300 m
- time interval: 1993-2004

11-year mean currents at 20 m on EKE from Aviso

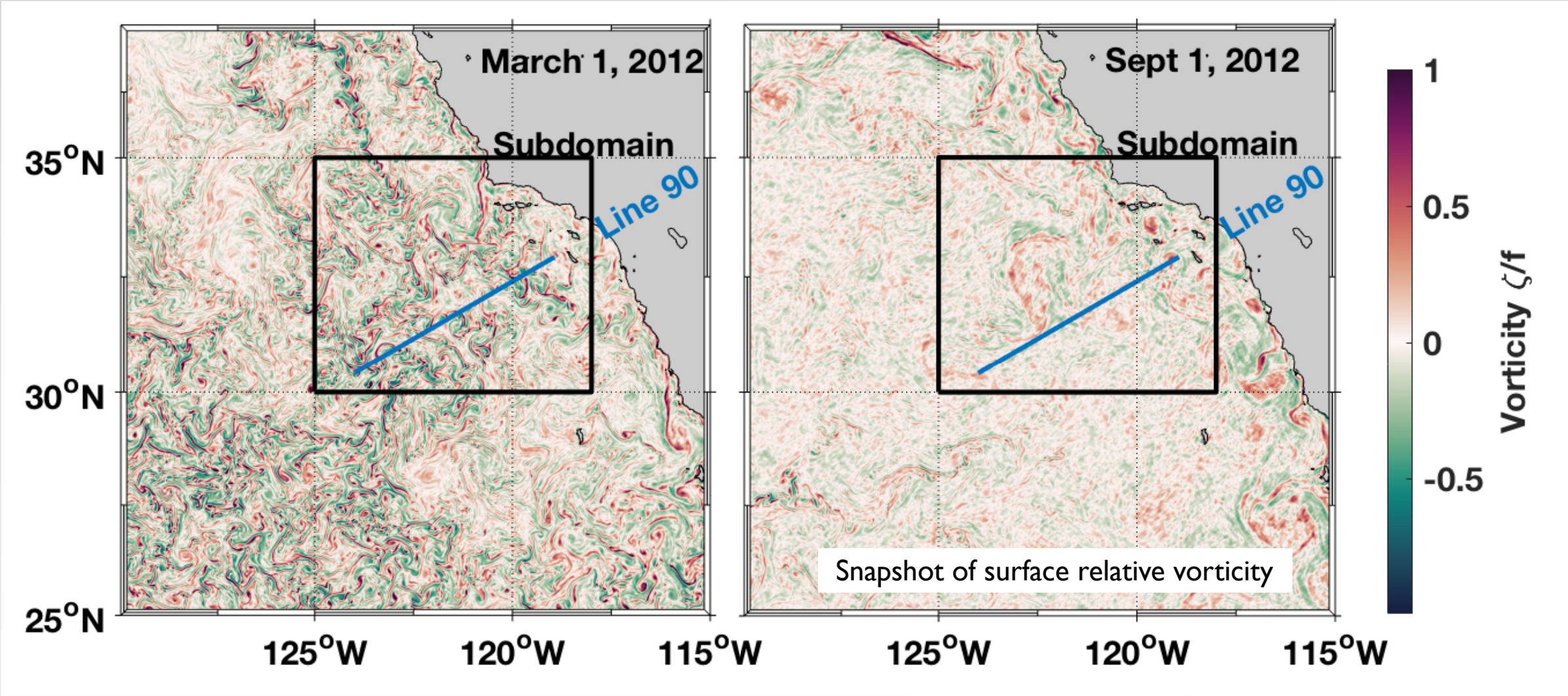


SSH from altimetry:

- Jason-1/2 w/ALES, the Adaptive Leading Edge Subwaveform processing (Jan 2002 - Aug 2016)
- AltiKa Ka-band (Oct 2013 - May 2016)
- Sentinel 3 w/delayed Doppler processing (Jan 2017 - May 2018)



Numerical model simulation



LLC 4320 MITgcm numerical simulations:

- global
- forced with tides & ECMWF
- 90 vertical levels
- 1/48° resolution; 1year simulation

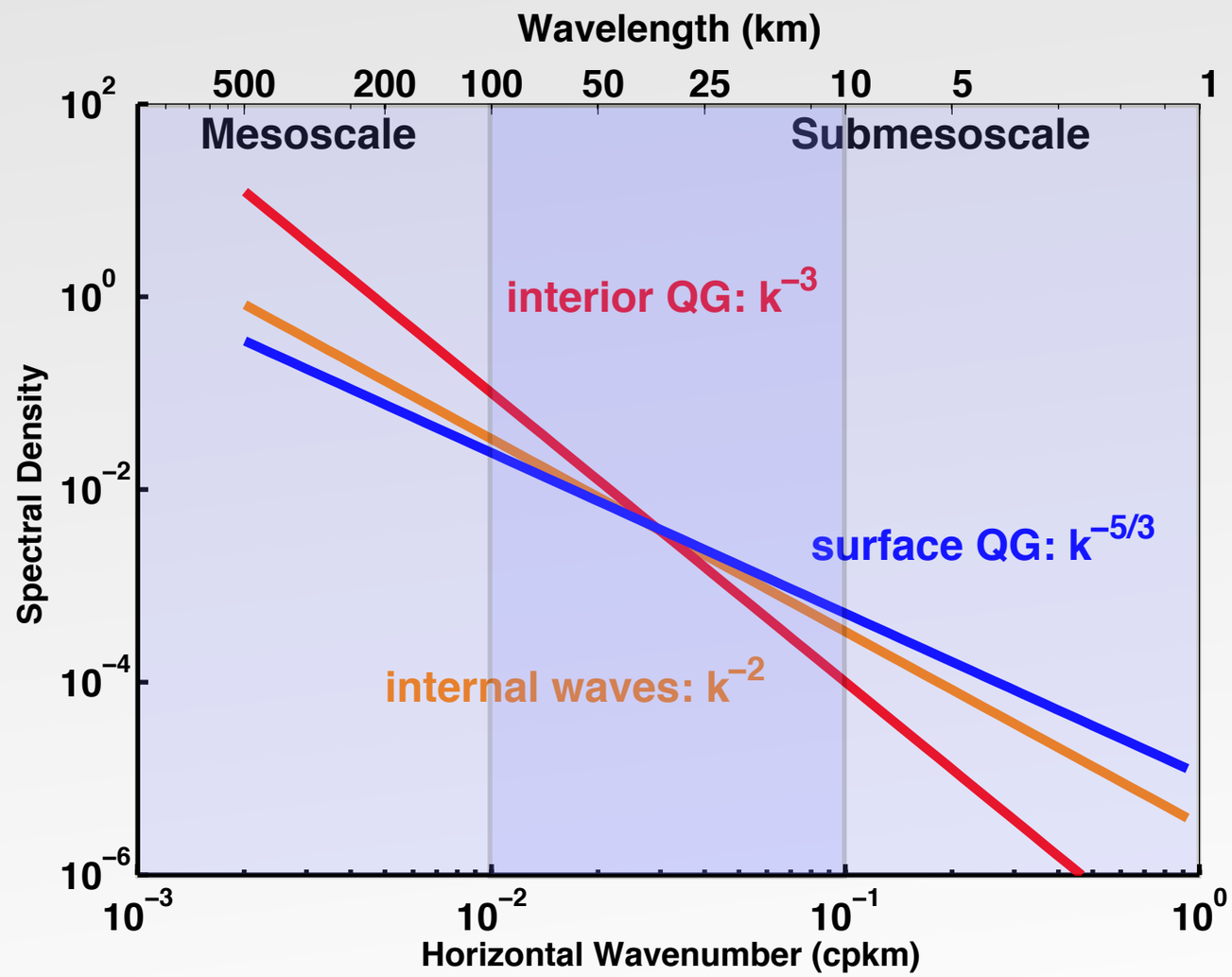
Inferring dynamics from horizontal wavenumber spectra:

What do we expect for kinetic energy spectra?

Isotropic Quasi-Geostrophy:

- interior QG predicts k^{-3} (Charney,1970)
- surface QG predicts $k^{-5/3}$ (Blumen, 1978)

Ageostrophic motions can project onto similar scales, e.g., inertia-gravity waves k^{-2} can flatten QG spectral slopes (Garrett & Munk, 1975)



Inferring dynamics from horizontal wavenumber spectra:

What has been observed for kinetic energy spectra?

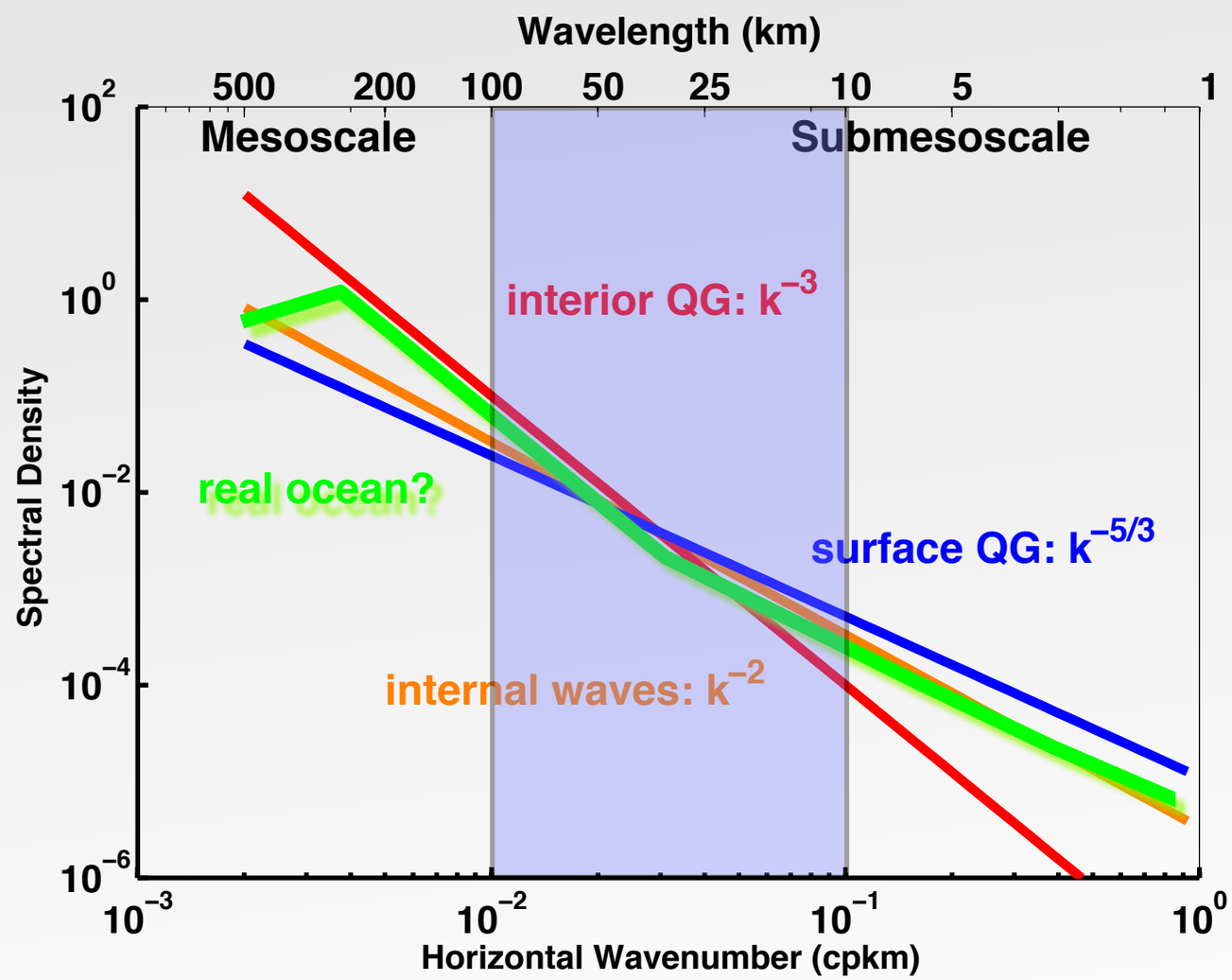
Real ocean spectra from strong baroclinic jets (Gulf Stream, ACC, Kuroshio) are consistent with

- interior QG (k^{-3}) at meso- to submeso- scales
- k^{-2} at submesoscales

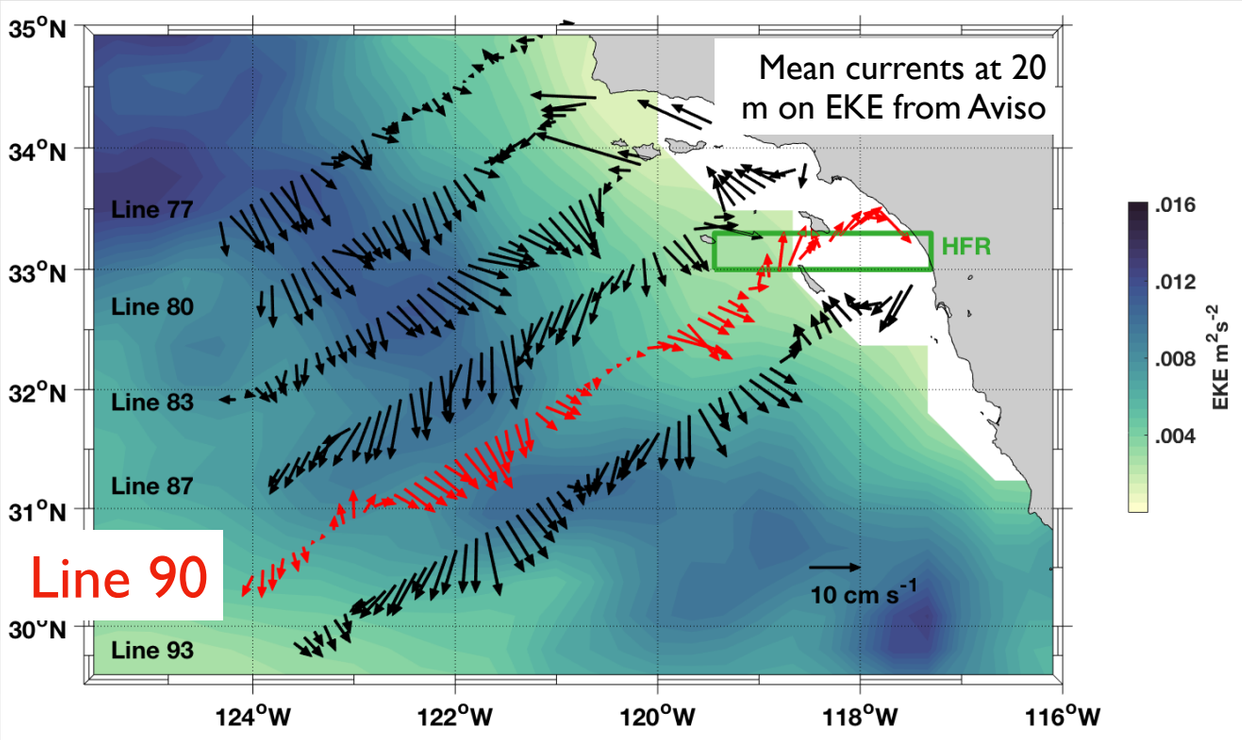
(e.g., Callies & Ferrari, 2013; Rocha et al., 2016; Qiu et al., 2017)

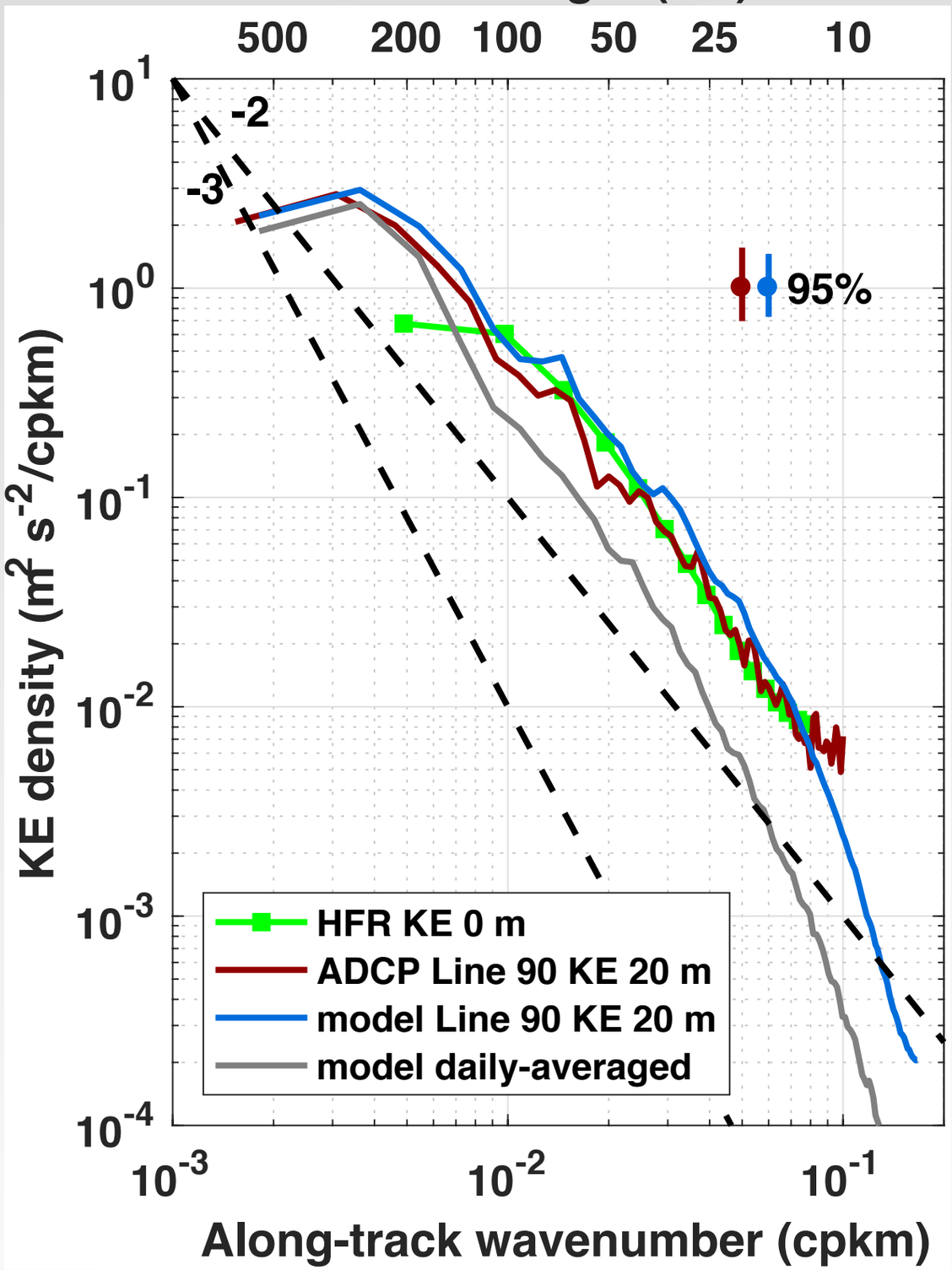
Is this ubiquitous? (Qiu et al., 2018)

Using observations and model to look at a weak mean flow region, southern CCS



In situ observations and model data: KE spectra





Line 90 across/along-track KE spectra:

- ADCP & model-hourly KE at 20 m & HFR KE at 0 m have similar shape, slope and energy levels
- Slope varies with wavenumber; about -2 for submesoscales
- Model-daily KE at 20 m has steeper slope due to less energy at wavelengths L < 200 km

(HFR courtesy Song-Yong Kim; Kim et al. 2011)

Inferring dynamics from horizontal wavenumber spectra:

Some properties of isotropic spectra:

- The 1-D (alongtrack) spectra will follow the same power law as 2-D (k^{-n})
- Ratio of across/along track KE components is useful diagnostic

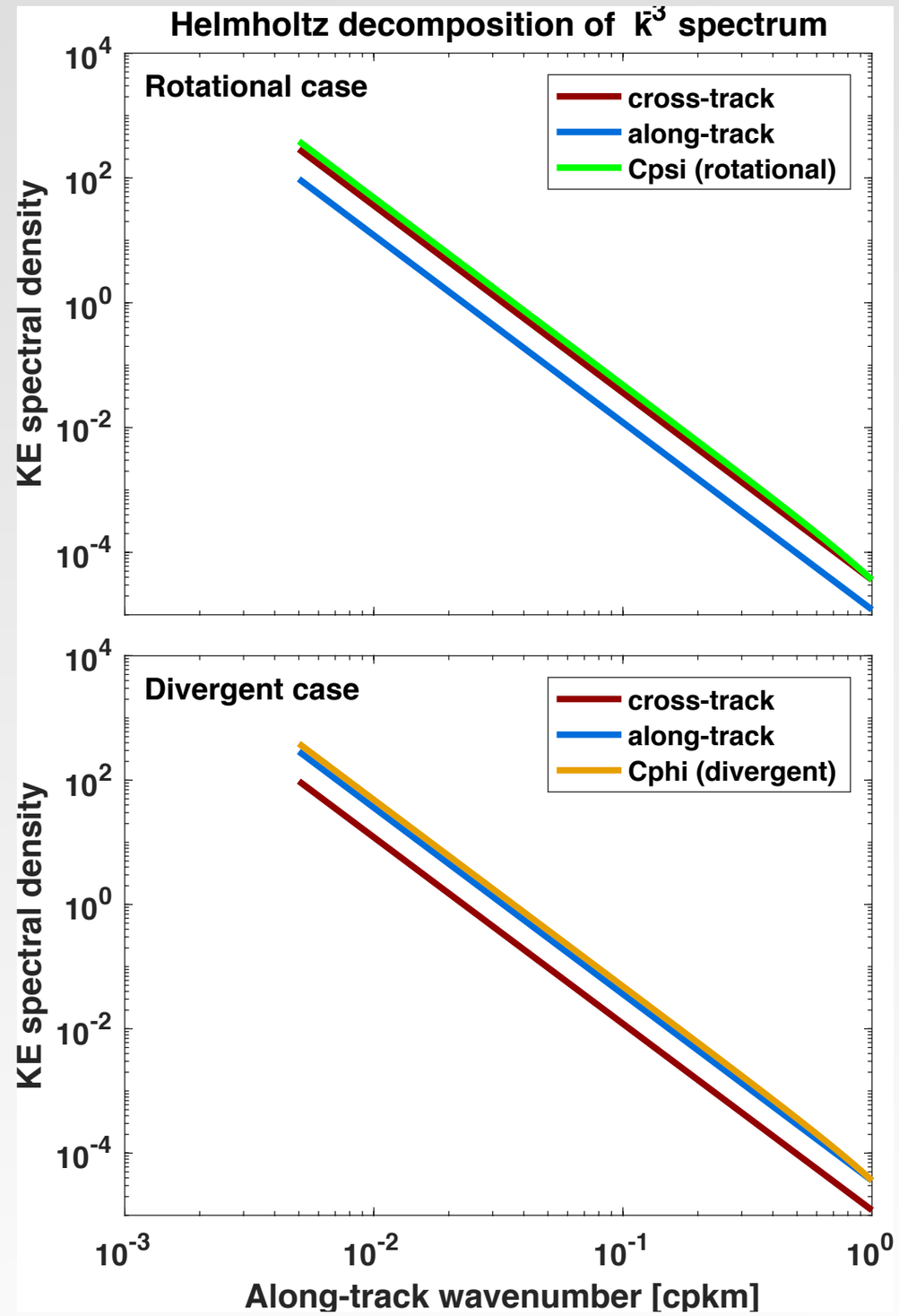
Across-track K_u and along-track K_v are related through the exponent n:

$K_u = n\ K_v$ purely rotational (nondivergent)

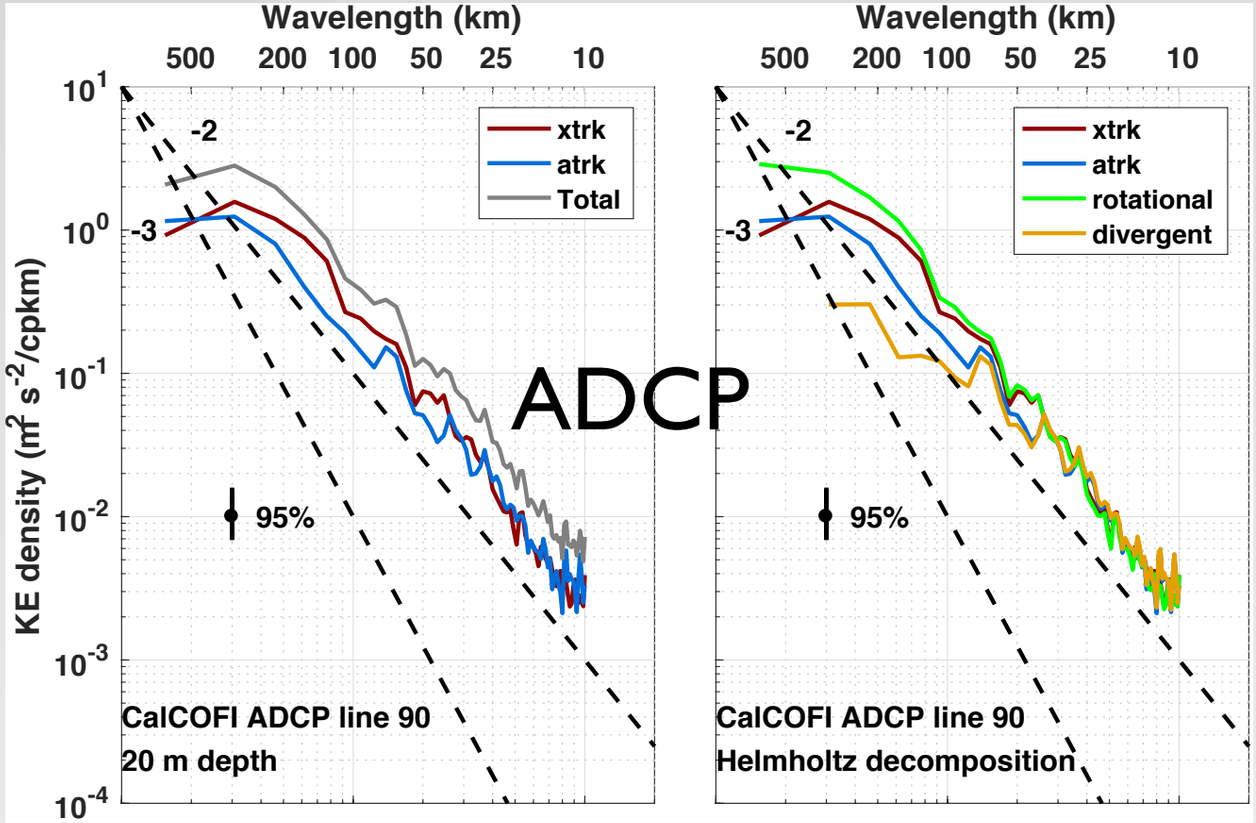
$K_v = n\ K_u$ purely divergent (irrotational)

- Helmholtz decomposition of 1-D spectra separates rotational and divergent components (Buhler et al., 2014)

(e.g., Callies & Ferrari, 2013; Buhler et al., 2014; Rocha et al., 2016)



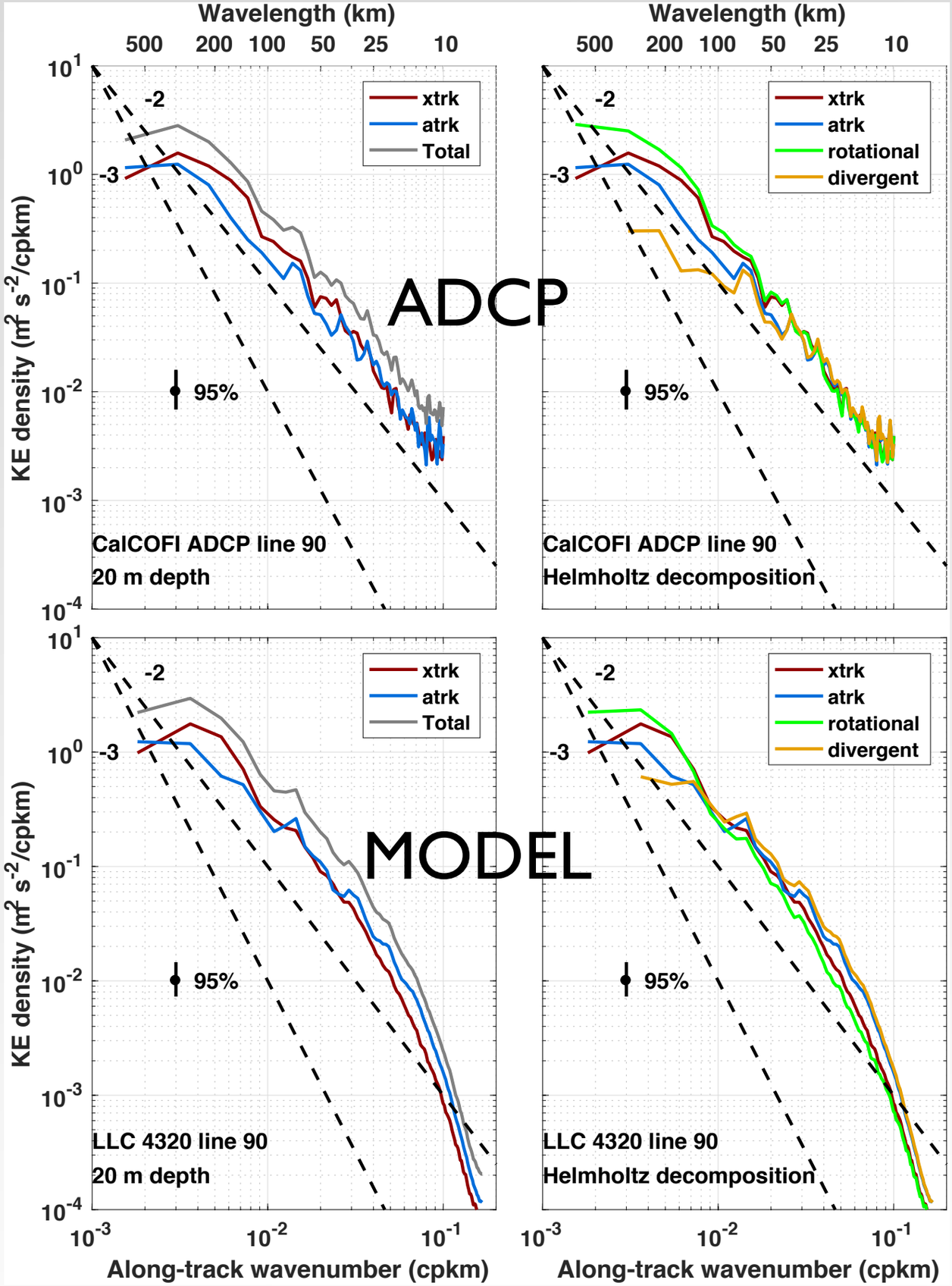
Helmholtz decomposition



ADCP

- Slope is close to -2
- 300>L>70 km: cross-track KE and rotational KE are dominant and ratio R ~1.8
- L<70 km: rotational and divergent about equal R~1

Helmholtz decomposition



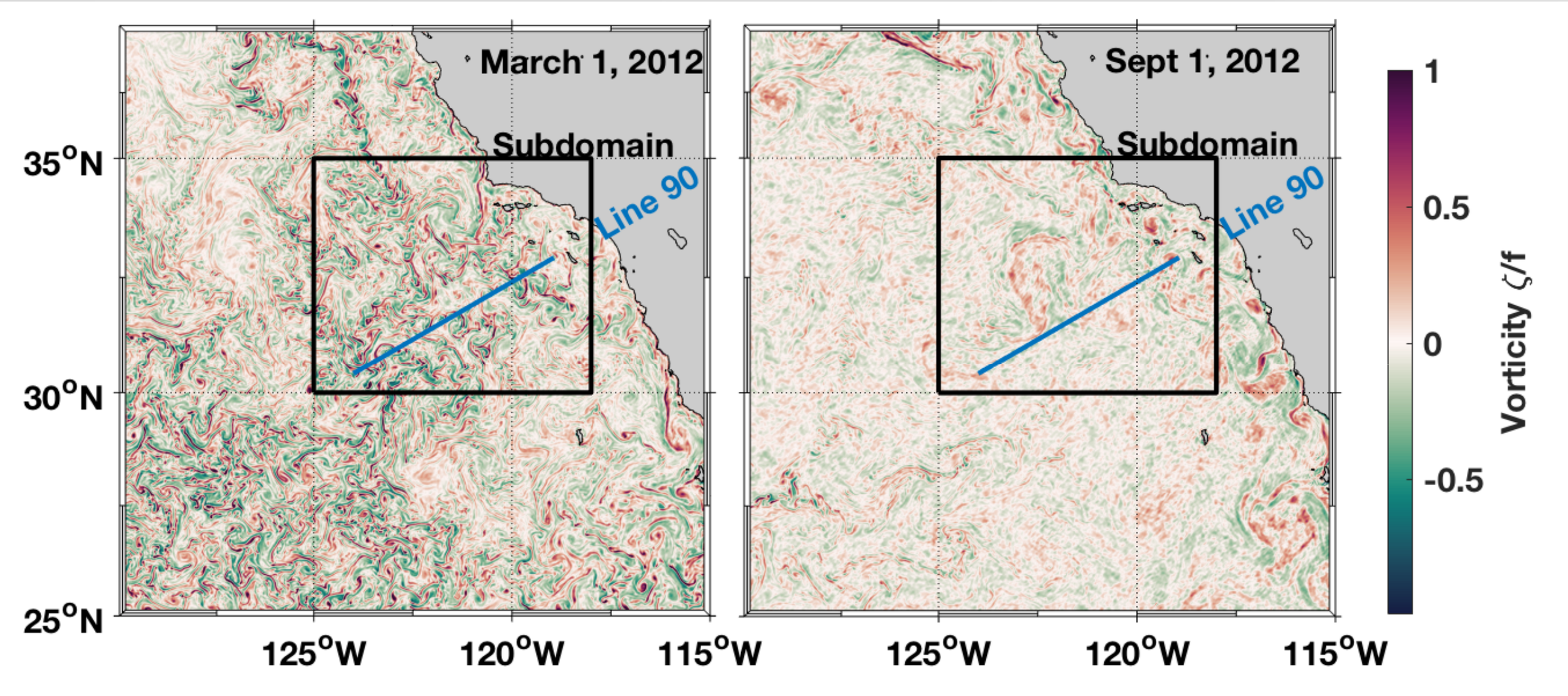
ADCP

- Slope is close to -2
- 300>L>70 km: cross-track KE and rotational KE are dominant and ratio R ~1.8
- L<70 km: rotational and divergent about equal R~1

MODEL

- Slope is close to -2
- 300>L>125 km: cross-track KE and rotational KE are dominant
- 125<L<70 km: cross- and along-track KE about equal, R~1
- L<70 km: alongtrack KE and divergent are dominant

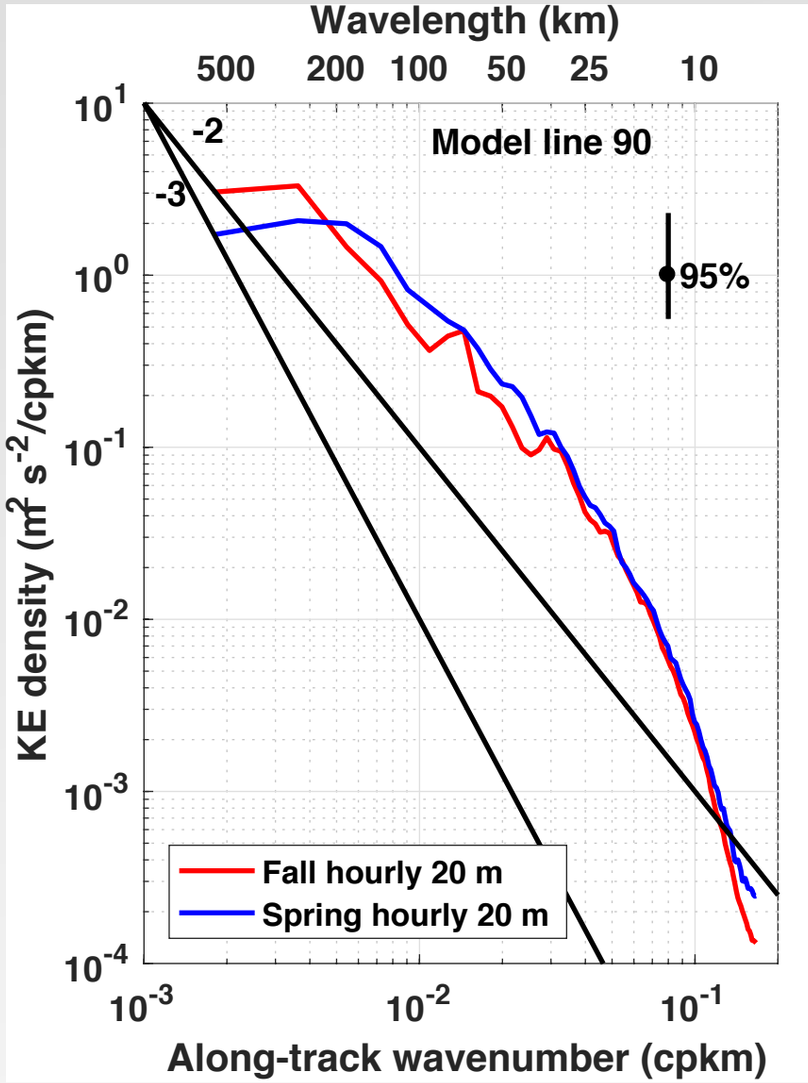
Seasonality



Model seasonal extremes are March and September

Model: seasonality

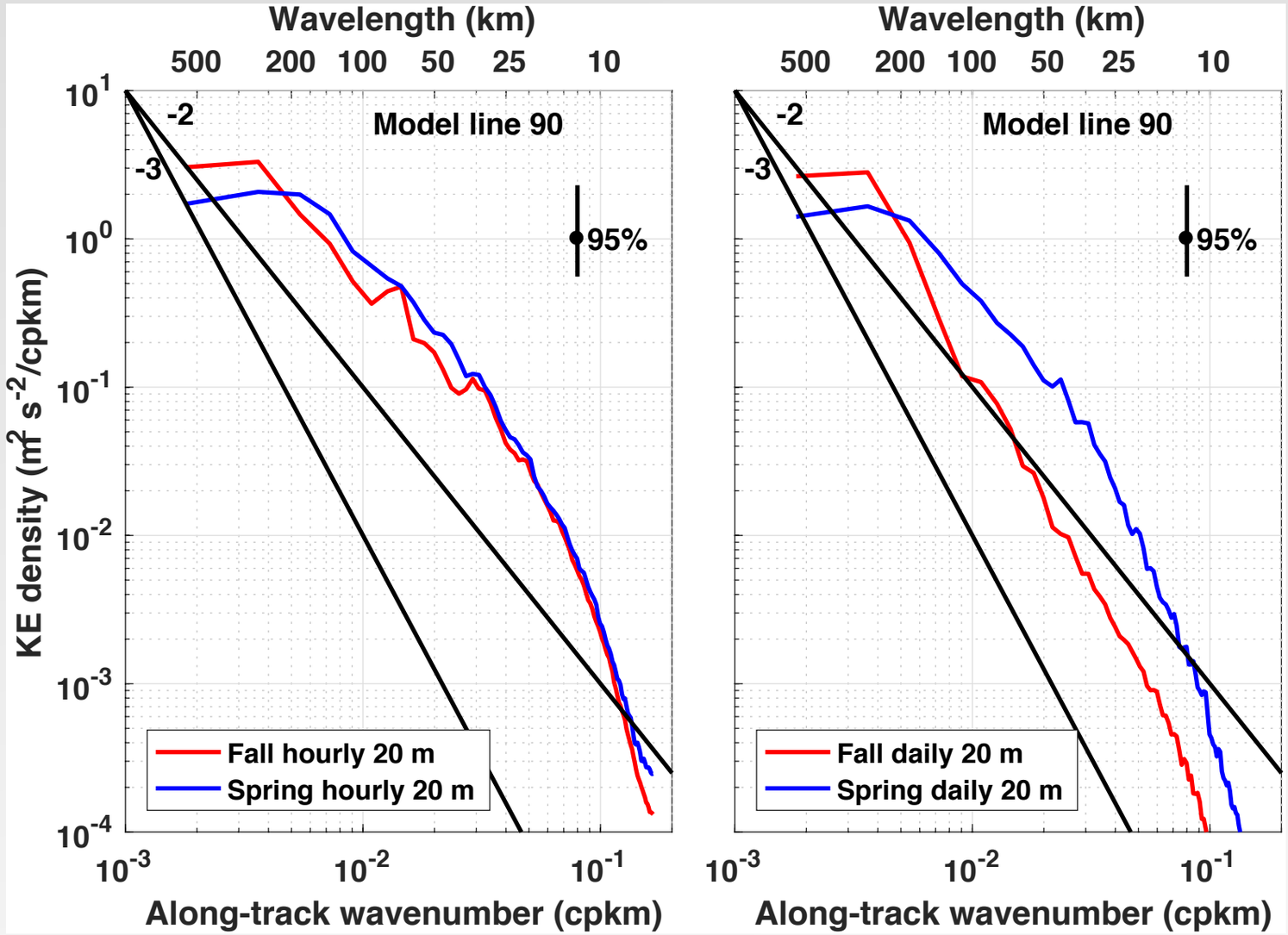
- No significant seasonality in model hourly KE spectra, except at L>200 km



Hourly

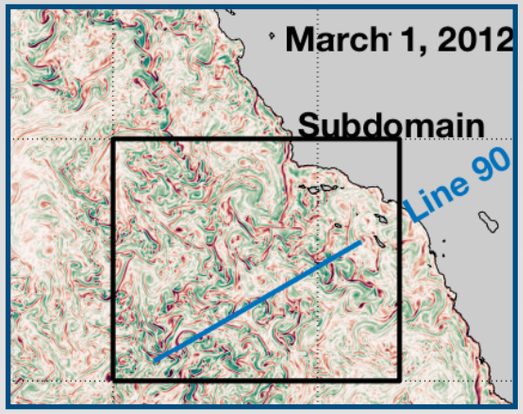
Model: seasonality

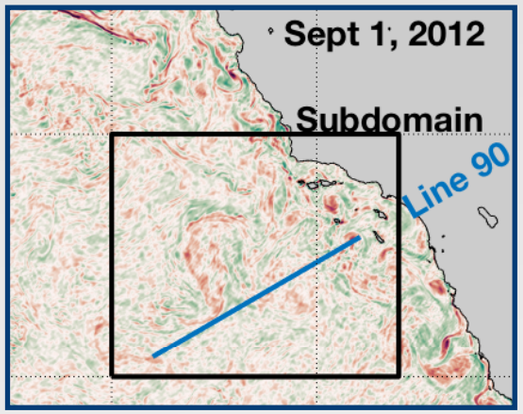
- No significant seasonality in model hourly KE spectra, except at L>200 km
- Significant seasonality in model daily KE spectra:
  - Higher KE in spring
  - Extends to about 100 m

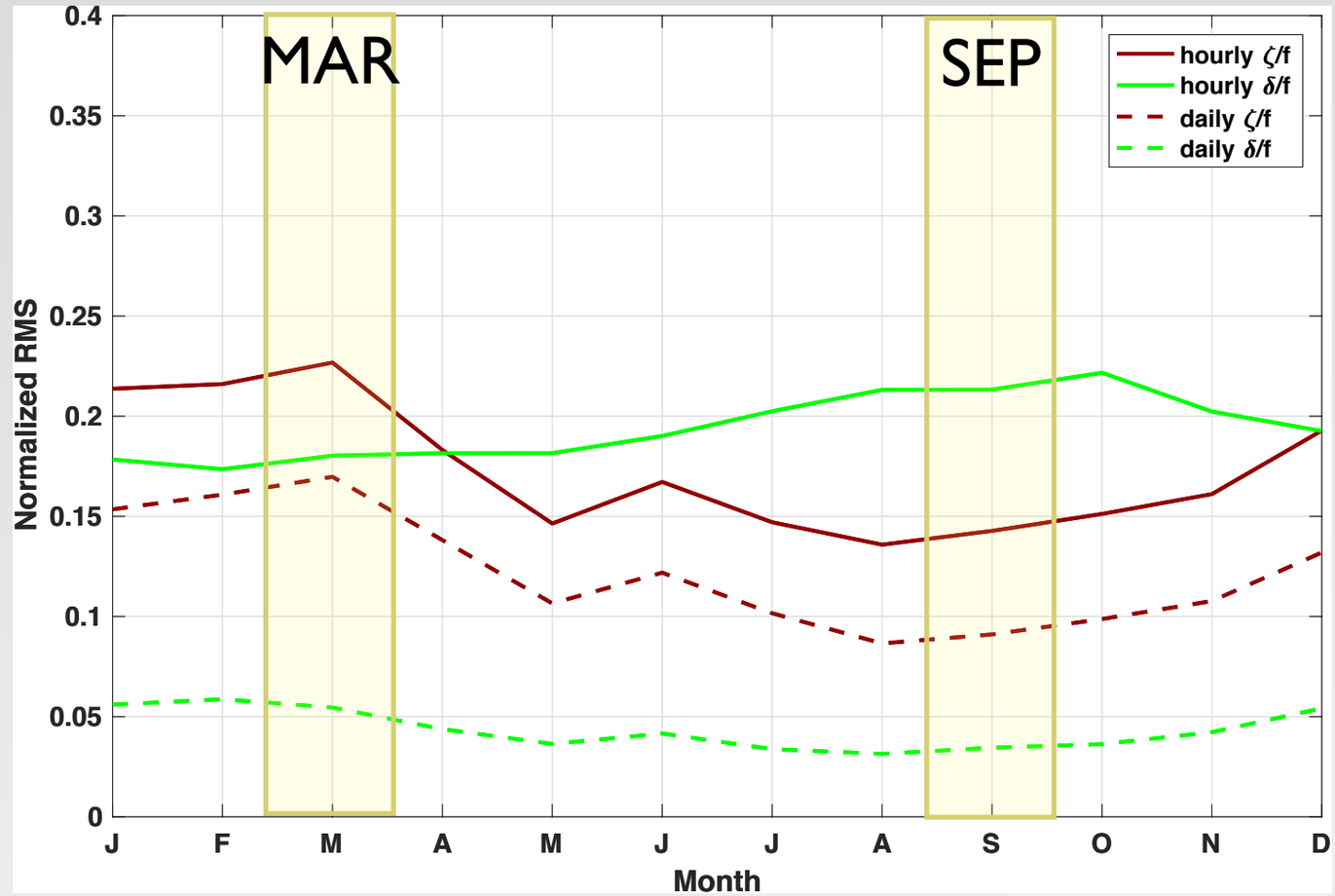


Hourly Daily

RMS vorticity (ζ/f) and divergence (δ/f)

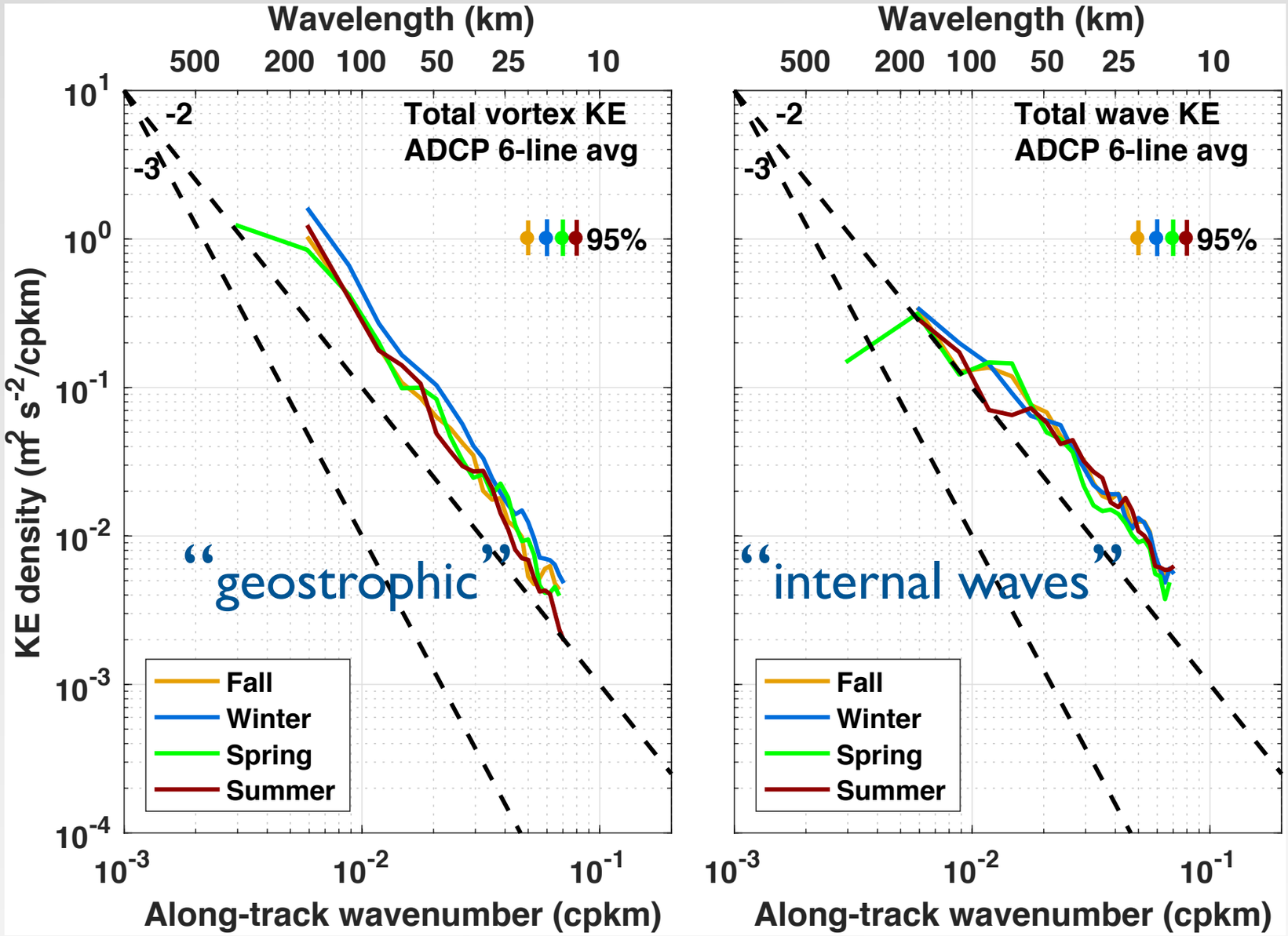






- Second order velocity statistics estimated over subdomain from hourly (solid curves) and daily (dashed) averages highlight seasonality at submesoscales
- Hourly (solid): seasonal cycle of vorticity (ζ/f) peaks in spring, out of phase with divergence (δ/f) that peaks in fall
- Daily (dashed): seasonal cycles are in phase, with only weak divergence

ADCP seasonality: Helmholtz and wave-vortex decomposition

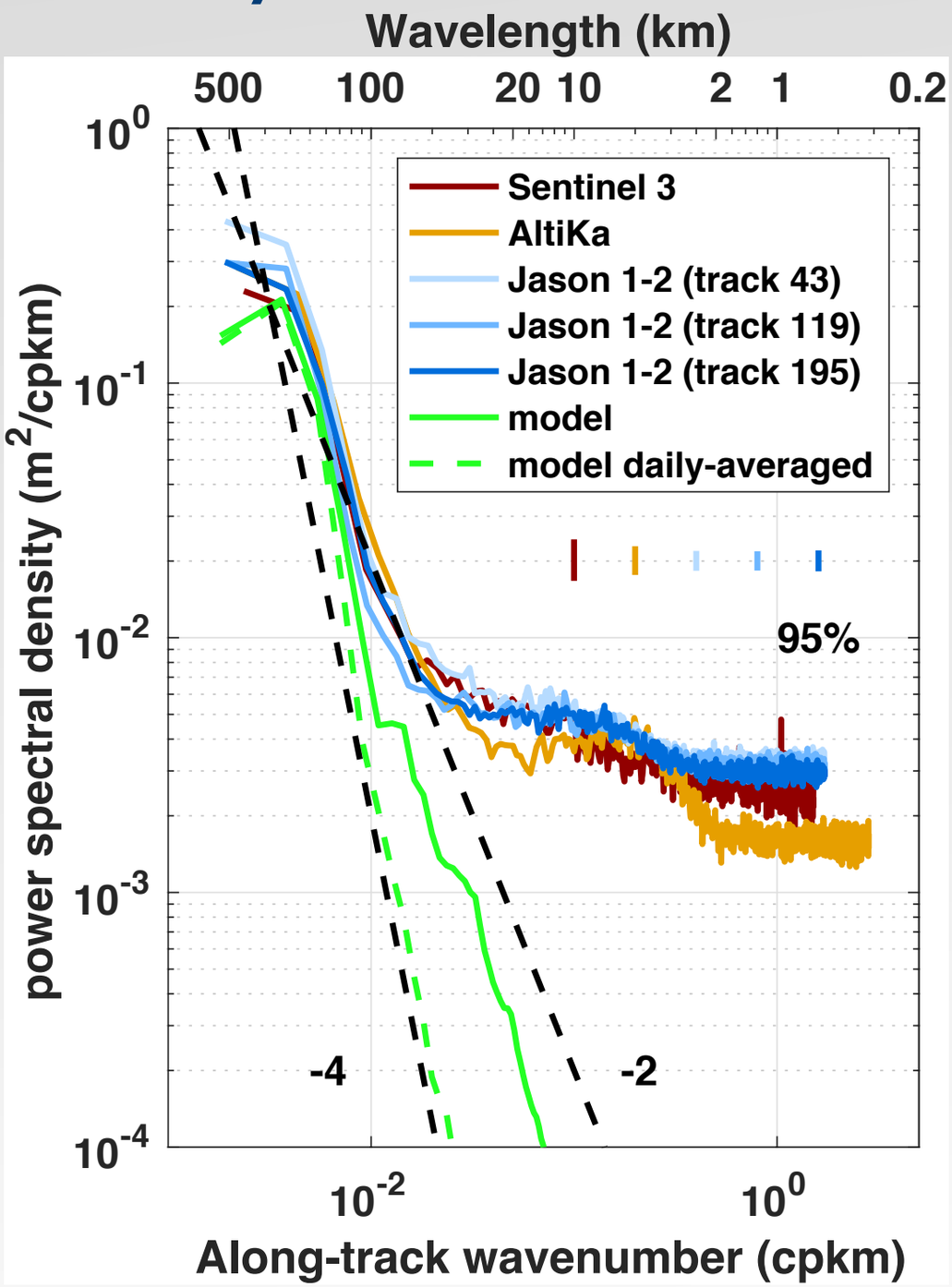


6-line wave-vortex decomposition:

weak seasonality in vortex component; highest in winter

SSH spectral density

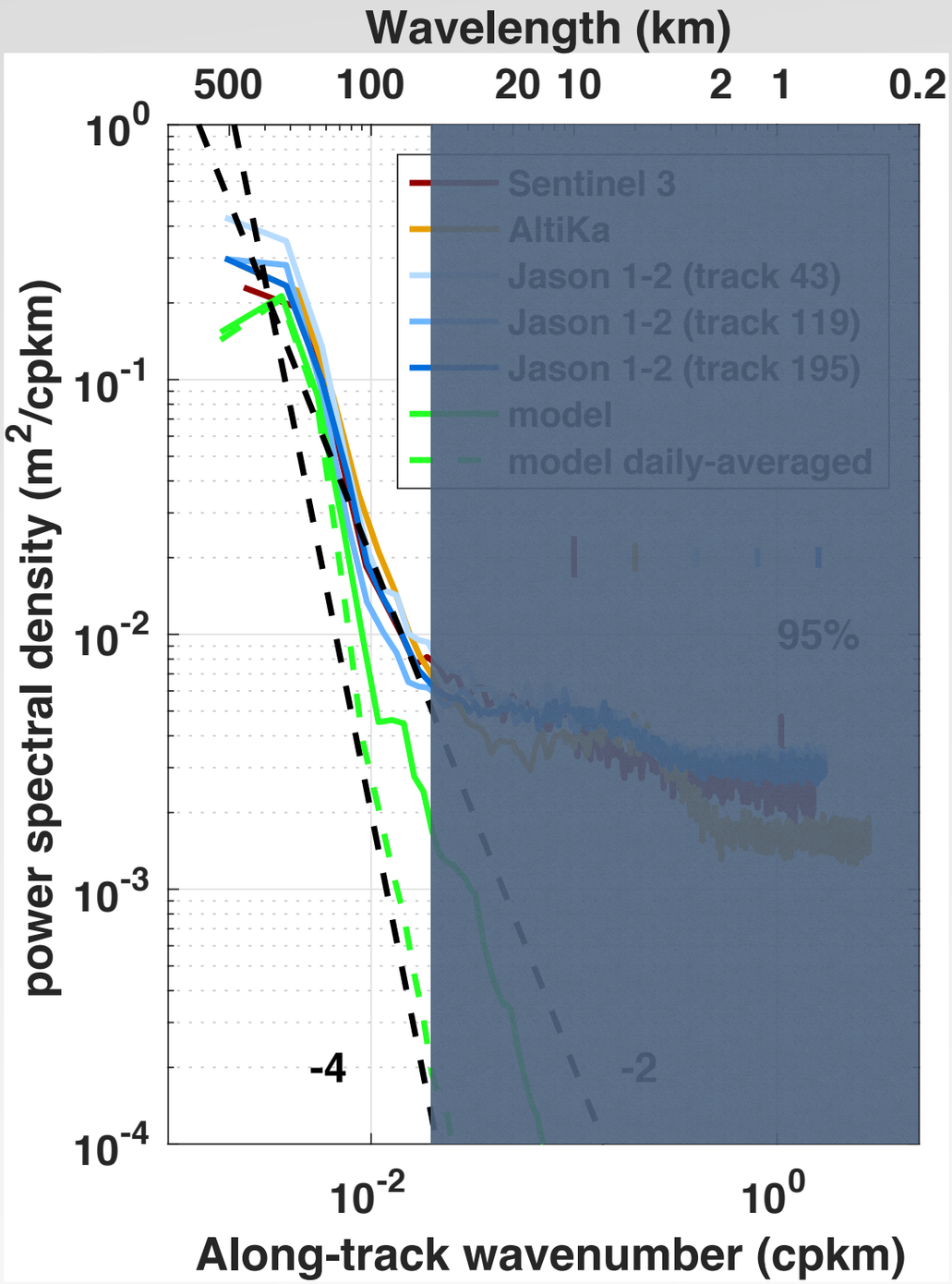
- Altimeter SSH spectra are red, with slope near -4 slope for 250km>L>70km
- Altimeter SSH spectra flatten for 70km>L>20 km.
- AltiKa and Jason SSH spectra have a spectral "bump" for 20km>L>2km.
- Altimeter SSH spectra are white for L<2km



See also Gille et al. ,"Assessing high-wavenumber spectral slopes (and effective resolution) in new altimeter products", Thurs. 17:00-17:15, Teatro Auditorium

Relating SSH and KE spectra in the balanced regime

- Altimeter SSH spectra follow -4 slope for 250km>L>70km, consistent with ADCP KE -2 slope and transition.
- Model and altimeter SSH spectra are consistent for L>125km.
- Model daily spectra flatten relative to hourly for L<125km.



See also Gille et al. ,"Assessing high-wavenumber spectral slopes (and effective resolution) in new altimeter products", Thurs. 17:00-17:15, Teatro Auditorium

Conclusions

- At scales between 10 and 200 km, upper-ocean KE spectra in the southern CCS follow an approximately -2 power law.
- Observed transition from predominantly rotational to divergent motions occurs at L~70 km with no change in spectral slope. Model transition occurs at longer wavelength, ~125 km.
- Observed and model-hourly KE spectra have weak seasonality. Phase cancellation may reduce KE seasonality.
- ADCP and model are consistent with 3 different altimeter data sets in the "balanced regime", L > 70 km.
- CCS results differ from strong jet/high EKE regions: flatter spectral slope, longer transition scale from balanced to unbalanced flow dominance. Similar to other low EKE regions.
- Geostrophic velocities can be diagnosed from SSH on scales larger than about 70 km in the southern CCS in all seasons.